Nanocantilever Property Based on Carbon Nanotubes

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Abstract

The mechanical and geometrical properties of carbon nanotubes (CNT), nanocantilevers beam from single walled carbon nanotube (SWCNT) material were investigated in this study. Therefore, a bundle of SWCNT in cylindrical geometry with 20 nm in diameter and 1 μm in length was fabricated in two nanocantilever devices: clamped-clamped and clamped-free positions and the foucus of this paper was on the latter design. In this case, the results showed that the first resonance frequency ω_0 of the nanocantilever beam from the measured SWCNTs' dimension and spring constant is about 100 MHz. Due to the exceptional mechanical and geometrical characteristic of SWCNT, the first resonance frequency found is high compared to that one made from mica (ω_0 = 20 Hz) or silicon (ω_0 = 14 KHz). The result obtained is expected to have potential applications in nanoelectromechanical system (NEMS) working with high resonance frequencies.

Keywords

Single Walled Carbon Nanotubes; Nanocantilever Vibration; Clamped-Clamped; Clamped-Free

Introduction

Carbon nanotubes with special electronic and mechanical characteristics have attracted much attention from many researchers in various fields. In fact carbon nanotubes are tiny tubes made of carbon atoms arranged in hexagonal patterns whose nanometer diameter and length are larger and about micrometers. The single walled carbon nanotubes (SWCNT) can be regarded as a rolled up piece of a graphene sheet, two-dimensional graphite plane, in a cylinder formed by wrapping up a regular hexagonal lattice. Such nanomaterials are promising materials in the area of nanoscience towards nanotechnology. Specially, the carbon nanotubes have found many applications in atomic force microscopy cantilever tip and actuators. This study is concerning the use of SWCNT as a nanocantilever beam with remarkable properties. The advantages result in high flexibility and stiffness of SWCNT beside its nanometer-scale geometry. In mechanic, resonnace leads system to oscillate with greater amplitude at some specific frequencies. High resonance frequency is needed and even small periodic driving forces can produce large amplitude oscillations. Moreover, at high resonance frequency, the system can store mechanical energy.

Experimental Set-up

SWCNTs, generated by the electric arc discharge method, were dispersed in ethanol solvent with an ultrasonic bath and sonicated further to promote uniform dispersion. A drop of SWCNTs solution was deposited on the electrodes patterned by photolithography as shown in Fig.1 that is an image obtained from the scanning electron microscopy SEM. After few minutes, the ethanol was evaporated and the SWCNTs were extended and stuck on the electrodes used as support. The SWCNT nanocantilever was designed in two devices: clamped-clamped and clamped-free positions.

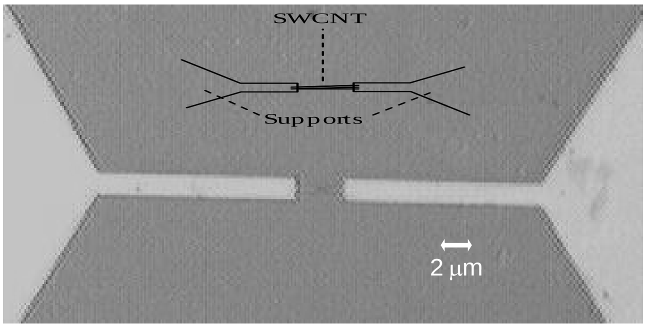

FIG.1 SCANNING ELECTRON MICROSCOPY OF SWCNT BUNDLE BETWEEN TWO ELECTRODES PATTERN AS NANOCANTILEVER CLAMPED-CLAMPED DESIGN

In the same figure, the concept is schematically illustrated and drawn.

The clamped-free design, the focus of this paper, is mean clamped at one end and free to move in the other end; in addition, the transverse motion of cantilevers is studied as well.

Fig.2 shows a high resolution electron microscopy (HREM) image of SWCNT bundle as nanocantilever

clamped-free design

FIG.2 HIGH RESOLUTION ELECTRON MICROSCOPY IMAGE OF SWCNT BUNDLE AS NANOCANTILEVER CLAMPED-FREE DESIGN

Analytical Calculation of Flexural Vibration of Clamped-free Cylindrical Nanocantilever

The theory of vibration modes of flexural cantilever is well known. The equation of motion of the cantilever is a differential equation of fourth order and can be briefly summarized as equation 1:

$$EI\,(\partial^4 Z/\partial x^4) + \rho S\,(\partial^2 Z/\partial t^2) = 0 \qquad (1)$$

where E is the modulus elasticity, I is the area moment of inertia, ρ is the mass density and S is the cross section; x is the coordinate in the longitudinal direction of the cantilever and $Z(x)$ is the deflection from the rest position of the length element at x.

The mode shapes for a continuous cantilever beam are given as:

$$Z_n(x) = z_0[(\cos k_n x - \cosh k_n x) - (\cos k_n L + \cosh k_n L)$$
$$(\sin k_n x \sinh k_n x)/(\sin k_n L + \sinh k_n L)]$$

where z0 is the vibrational amplitude and n is the mode number.

The resonance frequency for n, the mode number is given as: wn = k2n {(EI/ρS}1/2, for $k_0 = 1.875$, $S = \pi(d/2)^2$ where d is the SWCNT diameter about 1.2 nm, and the first resonance frequency of the nanocantilever beam calculated from the measured SWCNTs'dimension and spring constant is about 100 MHz.

In previous study, a cantilever beam from mica muscovite with a modulus elasticity of 1.7 10^{11} Pa, a mass density of 2.7 and the geometrical properties of 25 mm in length, 6 mm in width and 20 μm in thickness, the first resonance frequency ω_0 20 Hz have been investigated. Moreover, in the study of U. Rabe et al. used the silicon material and they found a resonance frequency ω_0 of about 14 kHz. By comparison, the resonance frequency of SWCNT is so high and the ration in case of mica muscovite or silicon is respectively about 5 10^6 and 7142 times. The comparative resonance frequencies dependent of physical properties of materials have been summarized in the following table.

Type of material	First resonance frequency
SWCNT	100 MHz
Si	14 kHz
Mica (muscovite)	20 Hz

The high value of the first resonance frequency of SWCNTs could be explained by their exceptional mechanical and geometrical characteristic. It is noted that high resonnace frequency leads system to oscillate with greater amplitude at some specific frequencies and the system can stores the mechanical energy.

Conclusion

The technique to fabricate nanocantilever using SWCNT has been described in the experimental part. The analytical method for calculation of the resonance frequencies is determined. The result have suggested that, due to the high resonance frequencies, the SWCNTs nanocantilever can possibly be used in nanoelectromechanical system (NEMS) working with high resonance frequencies.

The perspective of the nanocantilever for further investigation is to calculate the vertical shear force, which counteracts the object's weight and its influence on resonance frequency change.

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Khalil El-Hami was born in Khouribga (Morocco) in 1965 and earned his Ph.D in 1996 in material sciences and engineering from Université des Sciences et Techniques de Franche-comté in Besançon (France). After being a Senior Research Scientist for CNRS (Centre National de la Recherche Scieitifique) in Besançon, France, during 1996-1998, he joined Max-Plank Institute in Stuttgart, Germany for synthesis and production of carbon nanotubes. From 1998 to 2005, he moved to Kyoto University in Japan as associate Professor and was promoted to full Professor position in in the Department of Electronic Science and Engineering. His major fields of study is related to nanomaterials, nanocomposites for nanosciences towards nanotechnology.

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